Measurements of Standby Power—A Survey of the International Literature*

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Introduction

Our awareness of standby power[2] arose gradually, but can be traced back to measurements made over fifteen years ago. In the late 1980s, researchers studying residential buildings began to recognize the importance of "plug loads," "miscellaneous," or "other" to total energy use. By some estimates nearly 20% of residential electricity use was caused by the "miscellaneous" or "other," uses (Meier 1987). Standby power, that is, the electricity consumed by appliances when they were switched off or not performing their primary purpose, was recognized as a unique phenomenon soon afterwards (Meier, Rainer and Greenberg 1992; Sandberg 1993). Sandberg was among the first to perform a large number of standby measurements on consumer electronics and document the wide range in standby power use. (Sandberg also coined the term "leaking electricity.")

Researchers studying commercial buildings also began to recognize the importance of "plug loads" and, more specifically, office equipment, to overall energy use in commercial buildings (Norford et al. 1988). In the late 1980s electricity use of office equipment gained recognition as a unique end use (Nguyen, Alereza and Hamzawi 1988). Most of the attention has focused on reducing office equipment energy use by introducing a "sleep" mode, which computers, monitors, and other equipment would automatically enter after a period of inactivity. Creating a "sleep mode" became the first target of ENERGY STAR programs. There has been, until recently, less concern with equipment's energy consumption while switched "off" because it appeared to be a smaller problem. Since then many more measurements and estimates have been made.

This project seeks to understand the broader area of all low power modes, corresponding to both the standby and sleep modes. The present paper summarizes the most important recent measurements reported in the literature or available through personal communications. Unfortunately measurements have generally focused on either standby in the residential sector or sleep in the commercial sector. We have therefore divided the survey into two parts. The first part deals in the residential sector (and principally of standby power) and the second part with the commercial sector (principally sleep).

The Residential Sector: Measurement Approaches

Residential standby power use has been estimated in three separate ways:

- Whole-building measurements
- Bottom-up estimates
- New-product measurements

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[2] In this paper we refer to three basic operating modes: On, Sleep, and Off. Low-power refers to the combination of Sleep and Off. Previous LBNL papers have used Low-power as a synonym for Sleep. The term "Standby" is now generally being recognized as a power level and not an operating mode. Most devices achieve their standby power use when Off, so we sometimes use Standby to refer to the Off mode.

Details of the three methods are described below. Information collected for commercial buildings is significantly different, both in procedures and results, so these are discussed separately.

Whole-building measurements involve visiting a building and measuring the standby power use of every device consuming standby power. These consumptions are tabulated and reported for each building. Nearly all of the studies have focused on residential buildings. Ideally the sum of their measurements is compared to the consumption shown on the utility meter when all appliances have been switched "off" (Ross and Meier 2000). This provides a means of confirming that no appliances were overlooked, but it is often difficult to accomplish without inconveniencing the occupants. By monitoring a representative group of homes, a survey can establish a reasonably accurate and highly credible estimate of standby power use in that region. The problem, however is to develop a representative group of homes; most surveys rely on volunteers.

It is easy to overlook devices drawing standby power in homes. Most surveys made sincere efforts to measure all the devices but excluded a few because they were either too difficult to access (and the teams did not want to inconvenience the residents) or the teams simply failed to find all of the devices. For example, in the Colorado survey (Geller 2002), all of the homes had clock-controlled garden sprinklers (each with a large external power supply). The survey team did not notice them until after they had finished measuring four of the five homes. Other frequently overlooked devices included security systems, garage door openers, and exercise equipment. Some surveys, such as those undertaken in China (Warner et al. 2002), focused on the large appliances—TVs, VCDs, computers, etc.—and did not measure some of the smaller sources of standby power use. These omissions and oversights mean that actual standby power use was probably larger than reported.

It is also easy to be inconsistent with respect to defining and measuring standby power. A New Zealand (EECA 1999) and a few European surveys (Rath et al. 1997; Sidler 2000; Cremer and Boede 2001) included the energy consumed by heated towel racks and electric water heaters. There is no consistent definition of standby power in a refrigerator, so its contribution can either be absent or a significant fraction of the total. Virtually every survey accidentally (or deliberately) included some computer-related equipment in sleep modes (rather than off-modes). These actions will result in a higher estimate of standby power. Most of the careful studies describe the operating mode of the appliance when the standby power measurement was performed so that a reader understands the elements of the standby measurements.

Bottom-up estimates of standby power use are used to estimate either average standby per home or national standby power consumption. The estimate is based on measurements of standby in specific appliances and then multiplied by the average saturations of those appliances. For example, fifty measurements of TVs may show that the average standby power use is 4.0W. If the average home has 2.3 TVs, then the average home would have 9.2W of TV standby. The average house's standby power use would be assembled from the combination of field measurements of standby power and known appliance saturations.

The bottom-up estimate is accurate for common appliances (where there are typically large numbers of measurements and saturations are well known) but fails for minor appliances (where much of standby power use occurs). There is little information about the saturations of cordless phones, garage door openers, coffee makers, etc. As a result, bottom-up estimates probably underestimate actual standby power use.

In at least three countries (China (Warner, Lin et al. 2002), Argentina (Tanides, Dutt and Brugnoni 2000), and the United Kingdom (Vowles, Boardman and Lane 2001)), surveys have reported that occupants unplug appliances when not in use. This is probably the situation for home office equipment in the United States (and especially California after the electricity crisis of 2001) where a cluster of office equipment is often controlled by a single power strip. Annual standby energy use in these cases will be less than predicted by simple multiplication of installed power by the number of hours per year. Unfortunately, there are no reliable surveys of consumer behavior. Lin et al. (Lin et al. 2002) estimated the energy impact of different scenarios for China and found huge uncertainties in the final estimate of standby energy use. Anecdotal evidence in China suggests, however, that the trend is toward keeping appliances plugged in all the time.

New-product measurements involve visiting a store or factory and measuring the standby power use of many new products at one time. This is an excellent technique to quickly assess levels of standby; however, the results may not match in-home measurements. New TVs in Europe (Group for Energy Efficient Appliances 2002) and Japan (Energy Conservation Center of Japan 2002) consume far less standby power than those found in homes. It will take many years for the performance of the entire stock to catch up with the performance of the new products. Some organizations, such as the Energy Conservation Center of Japan (Energy Conservation Center of Japan 2002), the Group for Energy Efficient Appliances (Group for Energy Efficient Appliances 2002), the U.S. Department of Energy (Federal Energy Management Program (US DOE) 2002) and the Energy Star Program (Energy Star 2002) collect standby power measurements (submitted by manufacturers) and post them on the worldwide web. One technique to obtain measurements of existing units is to intercept them while being repaired (Rosen and Meier 2000). This technique is successful only for high-value appliances, such as TVs, VCRs, and computers.

Whole House Measurements

Twenty-one surveys of whole-house standby power consumption were compiled. Together, these surveys represent measurements of over one thousand homes around the world. These are listed in Table 1.

About half of the studies listed here have not yet been reported in the published literature. The largest survey involved 178 homes in France (Sidler 2000), followed closely by China (Warner, Lin et al. 2002) and several European countries. Six studies involved more than one hundred homes. Fewer than twenty whole-house measurements have been conducted in the United States. Studies consisting of measurements in a single home occurred in several countries.

The results are not fully comparable because each survey's measurement procedure differed in important details. Most studies defined standby power as the minimum power of a device while still plugged into the electrical mains. Thus, if the device has a hard-off switch, standby power use would be zero. (Other opportunities for differences are described earlier.)

Table 1 : Whole-House Measurements of Standby Power

Country/Region [Reference]	Homes	Year	Standby Power (W)	Standby Energy (kWh/yr)
Australia (Harrington and Kleverlaan 2001)	64	2000	87	760
Australia (Harrington 2001)	1	2001	112	980
Canada/Nova Scotia (Aulenback et al. 2001)	79	2001	38	329
China/Beijing (Warner, Lin et al. 2002)	42	2001	33	n.a.
China/Guangzhou (Warner, Lin et al. 2002)	115	2001	35	n.a.
Denmark (Sidler 2001)	100	2001	60	530
France (Sidler 2000)	178	1999	38	235
France/Paris (Lebot 1999)	1	1999	70	600
Greece (Sidler 2001)	100	2001	50	440
Italy (Sidler 2001)	100	2001	57	500
Japan (Nakagami et al. 1997)	36	1997	60	530
Japan (Nakagami 2001)	42	2000	45	398
Japan/Tokyo (Murakoshi 2000)	1	1999	80	700
New Zealand (EECA 1999)	29	1999	100	880
New Zealand/North Island (Roke 2000; Isaacs 2001)	2	2001	115	1006
Portugal (Sidler 2001)	100	2001	46	400
Sweden (Molinder 1997)	1	1997	80	475
United Kingdom (Vowles, Boardman et al. 2001)	32	2000	32	277
USA/California (Ross and Meier 2000)	10	2000	67	590
USA/California	4	2001	115	1010
USA/Colorado (Geller 2002)	5	2001	46	405
USA/California (Rainer, Meier and Greenberg 1996)	4	1995	84	736

Average standby power use ranges from 100–115 W in New Zealand and the United States to about 35 W in China. The weighted average of all the measurements was about 50 W. (Future studies will also include a population weighting.) The high values are somewhat misleading because these studies consisted of relatively few homes. In addition, the New Zealand measurements captured several heaters and defective appliances. The data can be more easily interpreted in Figure 1. Figure 1 shows that there exist wide ranges among the small measurement groups. The results from larger measurement groups are more consistent (and smaller). Further measurements are needed to improve both accuracy and confidence.

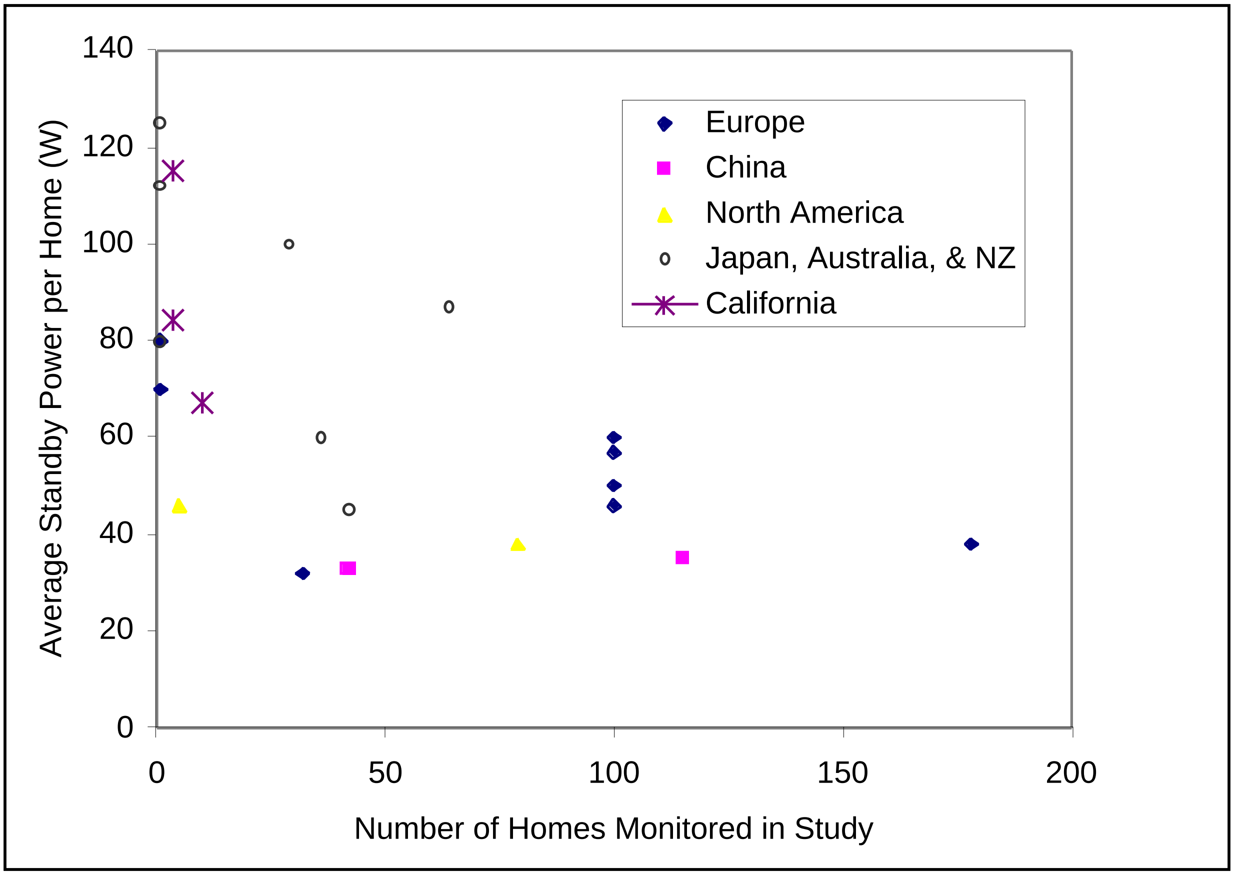

Figure 1. Measurements of standby power.

Three studies are reported for California. In 1995, Rainer et al. (Rainer, Meier et al. 1996) measured standby power in two new and two existing homes. They found an average of 84 W of standby, although the measuring procedure was not consistent and some appliances may have been in active or sleep mode while others may have been disconnected. Ross and Meier (Ross and Meier 2000) measured standby in ten Northern California homes. The results are summarized in Figure 2. These ten homes represent a diverse, but not statistically representative, cross-section of California homes. The average annual electricity consumption (total electricity) for the ten homes is very similar to the average for all homes in the PG&E service territory. These measurements probably captured nearly all of the standby power use because it was confirmed through measurements of whole-house power draw when all appliances were switched off.

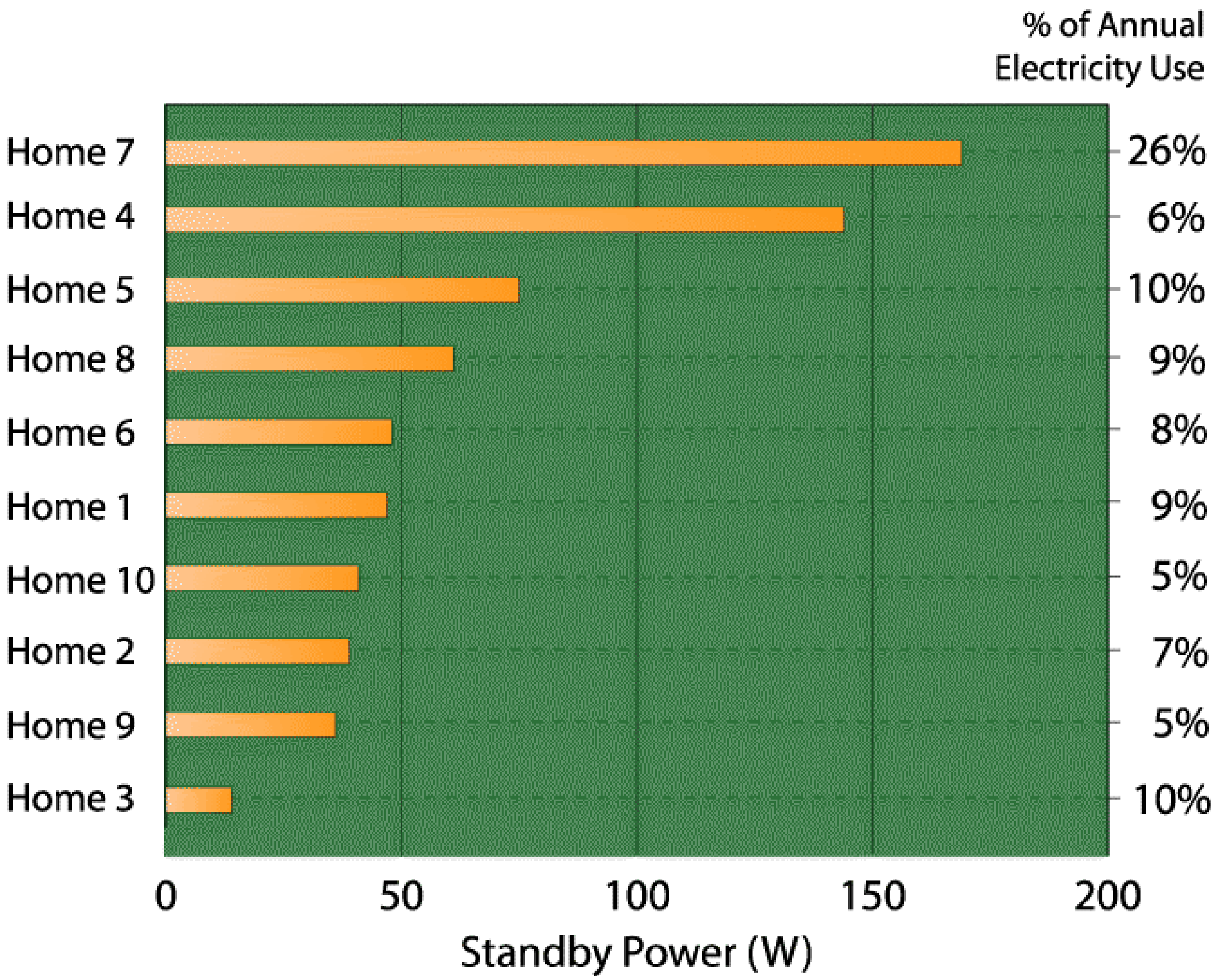

Figure 2. Measurements of standby power in ten Northern California homes.

The second study consists of an aggregation of four independent measurements. The results for one of the California homes is presented below in Table 2. This home had only 16 reported devices with standby. This is probably an underestimate because some common devices (such as cordless phones and a microwave oven) are not included.

Table 2: Standby measurements for one California house

Product	Energy Star	Model Year	Stand-By Power In Watts
General Instrument—ATT Broadband Cable Box		1998	34 W
Sony KV20V8—20” Color TV		May 98	14 W
Sony Slv-7790-HF—VCR	Yes	2000	13 W
“*Overhead* Door” Garage Door Opener		1975–1980	12.0 W
Sony KV271W77—27” Color TV		Dec 93	11 W
Bose Acoustic Wave—CD		2000	6 W
H. P. 660C DeskJet Printer		1995	5 W
Hitachi Laptop PC—PC-AP4800 AC Adapter	Yes	1998	4 W
Panasonic Ambience Clock Radio (10 Watt)		1995	3 W
Trektech In Door TV Antenna Amplifier		1998	3 W
Out Door Motion Sense Night Light (60 Watt Bulb)		2000	3 W
Intermac Time-All SB 811 (Clock Motor) Timer		1985	3 W
Second Timer		1985	3 W
Radio Shack—Realistic Clock Radio		1980	2 W
Regent HS8 Motion Sense Night Light—LED (7 Watt Bulb)		2001	2 W
Hamilton Beach Coffee Pot		2000	1 W
Total			**122 Watts**

Bottom-Up Estimates

Bottom-up estimates are typically based on many measurements (or estimates) of standby power for individual devices. An example of those measurements is shown in Figure 3 (Meier 1999) based on hundreds of measurements of new and existing products.

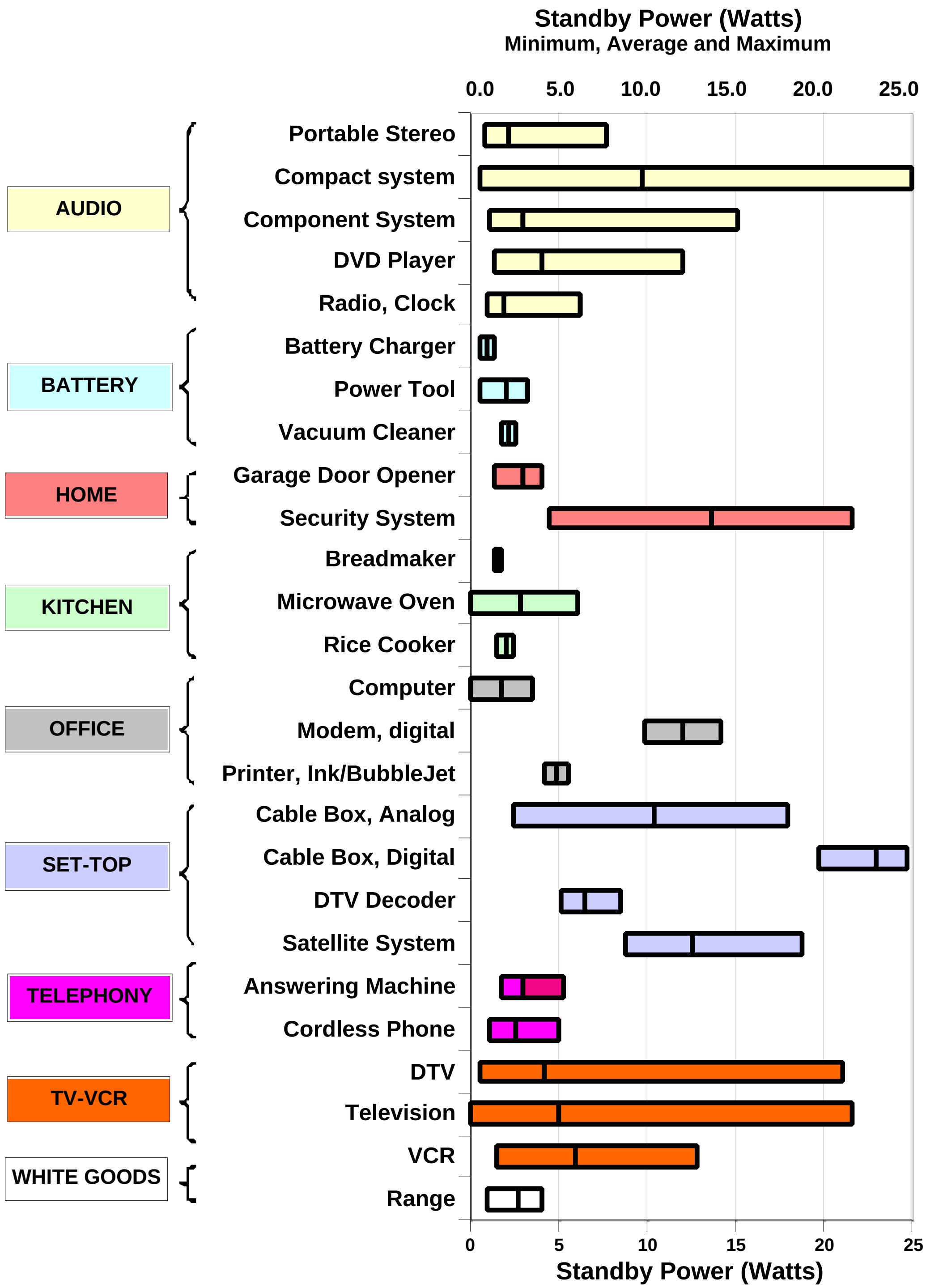

Figure 3 : Measurements of Standby Power

Eight bottom-up estimates of standby power use were compiled. These are listed in Table 4. Standby power appears to range from 7–86 W, corresponding to 3–12% of residential electricity use. Some of the estimates (such as those for Argentina and Switzerland) did not include all appliances, so these estimates are certainly lower than the actual situation. The Australian estimate, at 86 W, presumably excludes heat-generating appliances found in the field measurements, but Australia still appears to have the highest national level of standby power.

Table 4: Bottom-Up Estimates of Standby Power Use

Country (year) [Reference]	Average Standby per Home (W)	Fraction of Total Residential Electricity Use	Other Items Included after TVs, VCRs, set-top boxes
Argentina (2000) (Tanides, Dutt et al. 2000)	7	3%	None
Australia (2000) (Harrington and Kleverlaan 2001)	86	12%	All, but also included a few heating devices and defective units
Canada (2001) (Aulenback, Fung et al. 2001)	49		All
France (2000) (Sidler 2000)	38	7%	All
Germany (2001) (Rath, Hartmann et al. 1997; Cremer and Boede 2001)	52	n.a.	All and may include some heat standby
Netherlands (1995) (Siderius 1995)	37	10%	None
Switzerland (1999) (Meyer & Schaltegger AG 1999)	19	3%	Stereos, some rechargeable appliances, PCs
USA (1996) (Rainer, Meier and Greenberg 1996)	50	5%	All

The Commercial Buildings Sector: Measurements of Sleep and Standby

Similar measurements of standby power for commercial buildings do not really exist. Furthermore, the definition of standby power and low-power modes is less clear-cut. For example, should the power use of exit lights and battery chargers for emergency lighting be included? Power use while in sleep mode is also more important in commercial buildings because office equipment is present in larger quantities.

In Belgium, De Groote (DeGroote 2001) studied five office buildings in Belgium. He found that standby was responsible for about 10–15 kWh/m^2 of office space (corresponding to roughly 1.5 kWh/ft^2, or 0.17 W/ft^2). De Groote claimed that the standby equaled about half of the *total* electricity consumption of the best designed new office buildings in Europe. Some of this power use was certainly caused by equipment in their sleep mode (and perhaps some by equipment still in active mode). In Japan, Nakagami (Nakagami 2001) reported that standby was responsible for 10% of total electricity use in one commercial building that his team monitored.

It is also possible to make a bottom-up estimate of standby and low power use in commercial buildings. The estimate requires data on saturations of equipment in offices. Two major bottom-up studies of energy use of office equipment have been undertaken. The first (Kawamoto et al. 2001) estimated energy consumed in the three modes: active, sleep, and standby. (We used this study for estimates of office building standby in California.) The second, by Roth (Roth, Goldstein and Kleinman 2002) is more detailed but it was not possible to easily extract estimates for standby and sleep mode energy consumption.

Webber et al. (Webber et al. 2001) audited ten California office buildings. They counted the number and the activity modes of the major types of office equipment. We combined this information with crude estimates of standby power for each device to estimate a standby power intensity: 0.06 W/ft^2. This corresponds to the power intensity if all the equipment was turned off (and was in the standby mode). This is a lower limit because Webber et al.'s survey found that a large fraction of the equipment never entered the standby mode (because they remained in sleep or active modes during the night). This bottom-up estimate is about 1/3 of De Groote's measurement. These results are not inconsistent, because the bottom-up estimate probably underestimates actual standby, while the whole-building measurement captures much more than standby.

Discussion

These compilations give a global perspective on standby power use. Some examples are given below.

The individual surveys revealed the number of appliances with standby in the homes. U.S. and Canadian surveys found about 20 appliances with standby in each home. Urban Chinese homes had about 11 appliances with standby power. In all three cases, this corresponds to roughly 3 W per device. This rule of thumb appears to be surprisingly robust.

Inspection of the detailed data from each country suggests that standby power use of common appliances (TVs, VCRs, etc.) is higher in less developed countries (China and Argentina) than in the developed countries. This appears to be a caused by less efficient appliances and older appliances. Nevertheless, several large power plants could be eliminated simply by lowering the standby power use of Chinese TVs (for example) to levels found in Japan.

The European situation with respect to standby is now unusually well documented, through several large surveys. Standby in those countries accounts for 30–60 W per home. But three large regions have essentially no information about standby power: South Asia (India, Pakistan, etc.), South America, and Africa. It is not necessary to have comprehensive data but important variations appear in various countries that may influence policies to reduce standby. China has two unique aspects: the high saturation of unique video compact disk players (VCD) and an unusually high fraction of time when the appliances are unplugged.

The standby power use has only been measured in 16 California homes and there is no assurance that the results are representative of the statewide situation. However, standby represents a larger fraction of total residential electricity in California homes (compared to the United States as a whole) because California homes use less overall electricity and because California homes probably use slightly more standby in an absolute sense.

Is standby power use increasing or declining? The information presented here is not sufficient to determine trends. New TVs, VCRs, and a few other appliances have significantly less standby power use than older models. These new models are clearly beginning to lower in-home standby power use. It appears that Japanese homes are now experiencing a decline in standby power use (Nakagami 2001). In the rest of the world, the simple number of appliances with standby power continues to increase. New appliances, such as DVD players, are appearing that consume standby, and updated models of older, traditional appliances, such as rice cookers, washing machines, and toilets, now have standby power consumption. The net effect of these trends is probably a continuing increase in global standby power use.

Standby power is also important to understand because of its contribution to a home's energy use. The growth of standby power reflects a trend in residential energy use, from a situation where appliances are either "on" or "off," to appliances being always "on," but at different modes. This trend greatly complicates the practical aspects of monitoring a building. Operating hours and cycles becomes less of an indicator of energy use and electricity consumption is distributed among many more appliances. In a more general sense, the rise in standby power and low power modes (and the appliances that consume it) will make it more difficult to understand how occupants use energy in a building.

Essentially no standby data for commercial buildings exist in California or the rest of the world. If the power density estimate of 0.06 W/ft^2 is accurate, then standby is less than a tenth of lighting power densities. The amount of power density for all low power modes (standby or sleep modes) would be higher.

Measurement Gaps

We identified several gaps in measurements. These are summarized below:

Low power energy use in homes

Standby power use has been measured in fewer than 20 homes in the United States, and most of these studies ignored sleep mode energy use. A broader study is needed including relationship to active modes. Consumer behavior is also important: in what fraction of products have the occupants enabled sleep features and in what fraction are products actually disconnected (either unplugged or controlled via a power strip)?

Essentially no data exist, either through direct measurements or detailed bottom-up measurements. We also need to distinguish carefully between hard-wired and plug-connected devices.

Hard-wired standby devices

Safety codes now require hard-wired smoke alarms and ground-fault interrupt (GFCI) outlets in many rooms. These, plus certain HVAC components, garage door openers, security systems, and other devices, also draw standby. Together they may draw as much as 50 W per new home, but no measurements have been done.

Standby and sleep energy in commercial buildings other than office equipment

Many other devices in commercial buildings draw standby, including elevators, exit signs, emergency lighting, and HVAC equipment. No studies have examined these aspects.

Standby and sleep energy use in commercial buildings other than office buildings

The few measurements that exist for commercial buildings have focused on office buildings. An unknown amount of standby and sleep energy use occurs in other types of commercial buildings

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